

## Chapter 4

# Reinforcement and Repair

Sometimes a bridge outlives its usefulness. Tactical loads may be greater than the capacity of the existing structure, or the bridge may have deteriorated or been damaged. A well-designed reinforcement will usually increase a bridge's period of usefulness. The purpose of bridge reinforcement is to increase a bridge's load-carrying capacity. This can be done by adding materials to strengthen the component parts or by reducing the span length.

### BASIC CONSIDERATIONS

4-1. Reinforcing existing bridges can save time and materials. Using the bridges on established routes will allow LOC to be operable quickly. Use serviceable bridge components (such as abutments and piers) when available. The following factors may influence reinforcement plans:

- **Maintenance reduction.** Reinforcing a bridge will often eliminate the need for long detours and difficult bypasses with attendant maintenance and traffic problems. Smooth deck surfaces will ease traffic movement.
- **Weather conditions.** Heavy rains that increase the stream's flow and render bypasses and fords impassable may dictate the need for bridge reinforcement. Anticipate such conditions to affect timely reinforcement measures.
- **Tactical bridging assets.** Reinforcement of existing bridges may allow the release of tactical or LOC bridging assets. Although the M2 Bailey-bridge components are often used for expedient reinforcement, other types of bridging (including fixed and floating types) may be released.

### CONSTRUCTIONS FACTORS

4-2. Many factors influence the final decisions about reinforcement construction. Construction methods depend on the site locations, the equipment available, and the nature of the repairs.

4-3. When selecting a construction site, consider the—

- Parts of the original structure that are still usable.
- Type of bridge and the span lengths.
- Characteristics of the waterway (particularly the use of additional bents or pile piers).
- Condition of the approaches to a reinforced bridge.
- Available alternate sites.

4-4. Standard steel and timber units that the military stocks are preferred over civilian materials. When there is an adequate supply of military

materials, the construction quality and speed is better and repairs are better accommodated. Sometimes only civilian resources will be available.

## CONVERSIONS

4-5. A bridge may be converted from one type to another (for example, converting a railroad bridge to a highway bridge). Converting a highway bridge to a railroad bridge is seldom practical since railroad loadings are usually heavier than highway loadings. *FM 5-277* describes the use of panel-bridge components for railroad-bridge construction.

4-6. The bridge shown in *Figure 4-1* is a one-lane railroad, through-girder bridge. The same construction could be used for other types such as a deck-girder, a deck-truss, or a through-truss bridge. The same principles also apply to installing a two-lane highway deck on a double-track railroad bridge. Many railroad bridges have less than the required 18-foot roadway width for two-lane military highway traffic. A through-girder railroad bridge may be able to be converted to a two-lane military bridge (*Figure 4-2*).

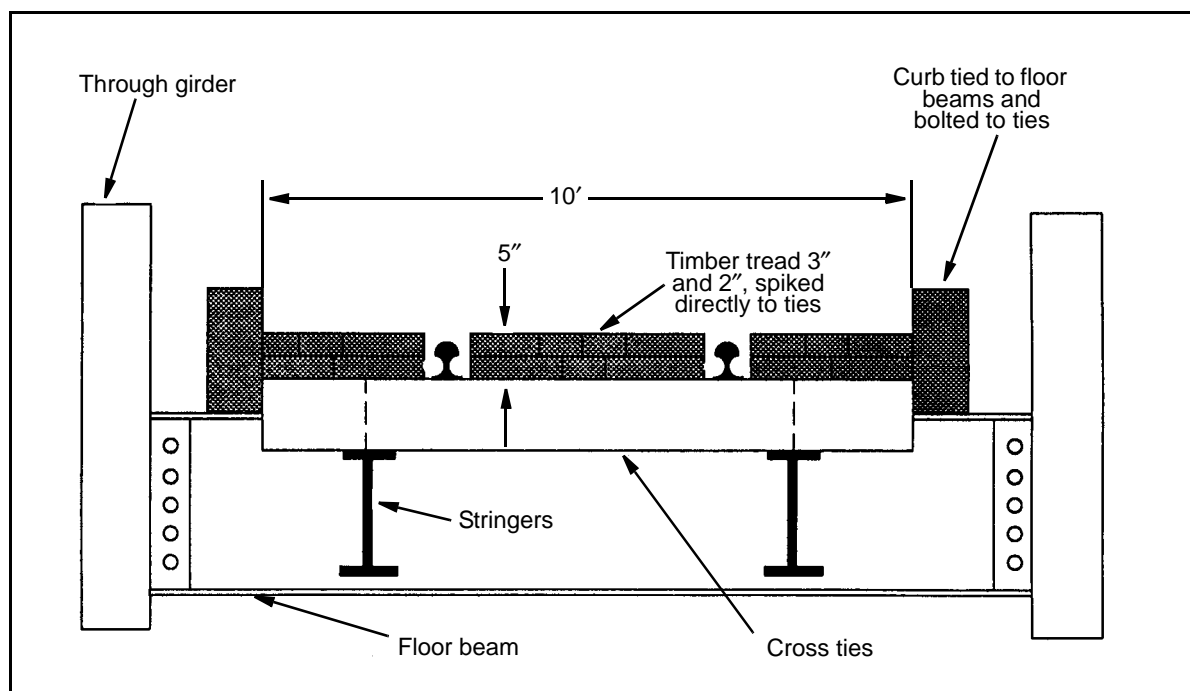
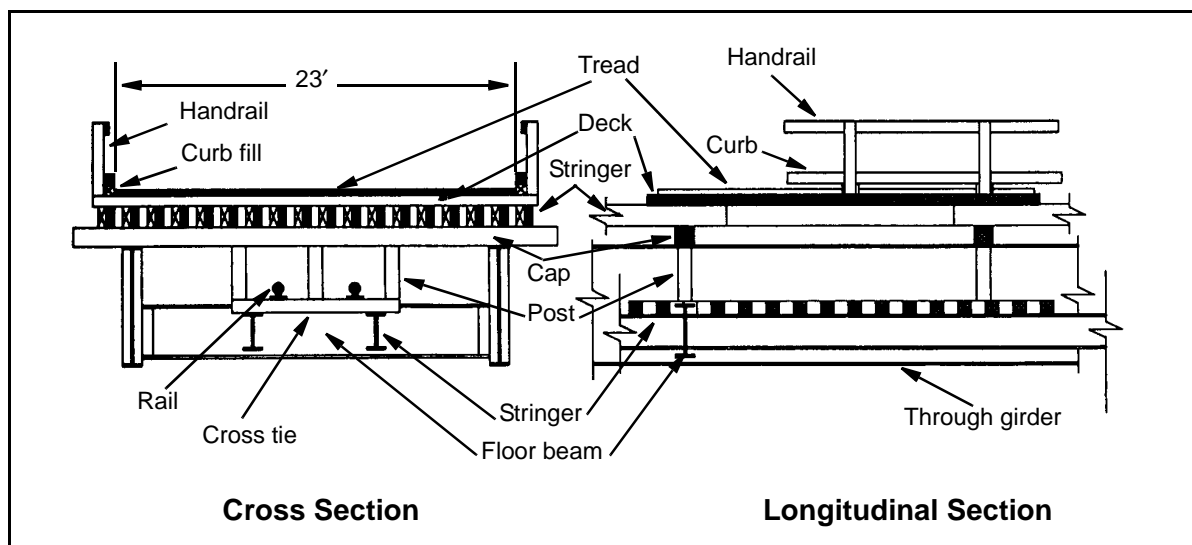


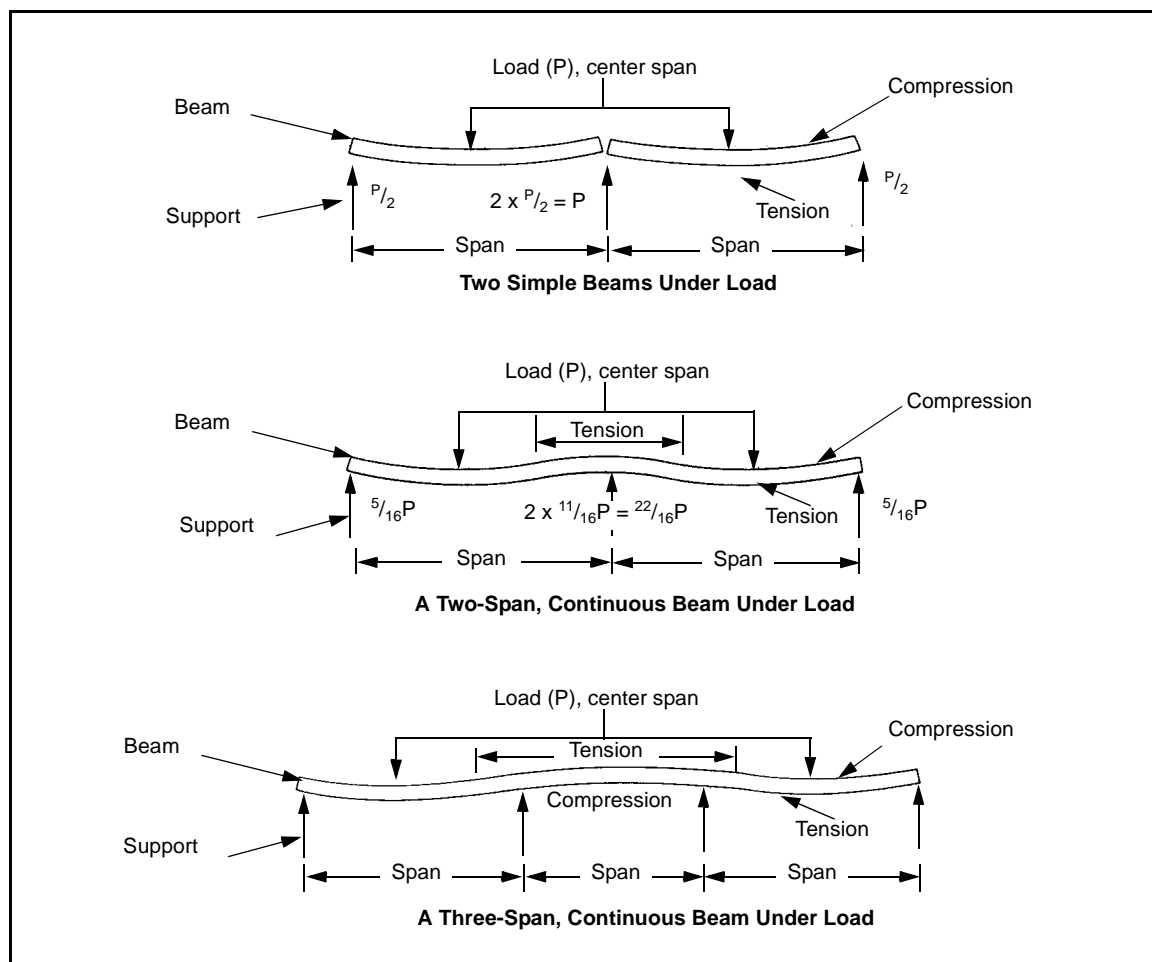
Figure 4-1. Conversion of a One-Lane Railroad, Through-Girder Bridge to a One-Lane Highway Bridge

## CONTINUOUS SPANS

4-7. Civilian bridges are frequently designed with continuous spans. A continuous-span bridge spans one or more intermediate supports without a break in the main load-carrying members. The top portion of the stringer is in compression over the major part of the span and in tension over the intermediate supports. Conversely, the bottom portion is in tension over the major part of the span but is in compression over the support (*Figure 4-3*).



**Figure 4-2. Conversion of a One-Lane Railroad Bridge to a Highway Bridge**



**Figure 4-3. Stress Reversals in Continuous-Span Structures**

4-8. When an ordinary, noncontinuous truss is propped up by bents or other supports are placed under the lower-chord panel points, the effect for which a truss was designed is reversed. Some truss members are designed to carry tension and others are designed to carry compression. By adding supports to a simply supported bridge, its condition may become continuous. This continuity may cause stresses to reverse so that the tension members become compression members resulting in failure. Furthermore, the magnitude of stress may increase. In general, compression members are heavy enough to carry tension but lighter members designed for tension ordinarily will not resist compression. Continuous trusses or trusses made continuous by new construction should be carefully analyzed by a qualified engineer to ensure that the propping of the tension members will not cause a stress reversal.

### **Advantages**

4-9. A continuous design is somewhat more economical regarding materials for long spans because of the reduction of the midspan moment due to continuity. Also, deflections of the spans are greatly reduced due to continuity.

### **Disadvantages**

4-10. Uneven settling of supports may occur when all the foundations do not rest on substantial soil. If a pier settles appreciably under load, the settling creates added stresses that may be detrimental to the superstructure.

## **HASTY OR EMERGENCY REPAIRS**

4-11. Emergency repairs are usually governed by the need for an expedient crossing, with immediate need dictating the capacity and permanence of the structure. Where possible, use standard items to expedite repairs (including Bailey-bridge components). If tactical bridging or standard items are not available, expedient methods will often satisfy repair requirements, assuming that most emergency structures will later be reinforced, replaced, or repaired. Bridge structures, site characteristics, and subsequent repair methods vary.

4-12. An engineer commander will select the repair method. This decision is based on the—

- Type of bridge.
- Nature of damage.
- Tactical situation and bridge requirements.
- Site characteristics (including usable bypasses).
- Available troops and equipment.
- Standard-stock bridging materials, the available accessories, and the time needed to get them to the site.
- Available local civilian materials.
- Time needed to perform the bridge repair versus the time needed to establish a detour or prepare a bypass.
- Skill and ingenuity of the engineers and construction force.

## REPAIRING GAPS IN BRIDGE DECKS

4-13. The most common failure or damage to a bridge is to the deck. Partial demolition or structural failure of the flooring, stringers, or arch crowns may cause gaps. The discussion below assumes that the original deck or the approaches on both sides of the gap are still intact or that adequate support exists around the same elevation as the undamaged deck.

### Considerations

4-14. Use a military bridge design when developing a plan for deck repair. Consider the—

- Moment and shear capacities of the stringers, flooring, trusses, and so forth.
- End reactions of added components, including the rated capacity and the dead load of the structure.
- Bearing capacities of the end-support devices (which may require special care at some locations). For example, unless the computed end reactions are extremely small and can be placed anywhere on the deck of the remaining structure, employ special measures to support end reactions of the new sections directly over the piers or other supports.
- Resistance to impact where a change in deck elevation occurs (special end ramps may be necessary).
- Maximum slope of long ramps for traction (special deck surfaces may be necessary for traction).

### Expedients

4-15. **Deck Balk.** When assembled as simple spans, deck balk from the M4T6 floating-bridge set can bridge gaps up to 45 feet.

4-16. **Bailey-Type Panel Bridging.** This bridging is the most versatile type of military stock bridging and can cover gaps up to 210 feet with a single-span structure. However, Bailey panels require more time to place than balk and may require more time to install than emergency expedients, depending on the circumstances. Some considerations are the gap length versus feasible bypasses, the availability of local materials versus availability of Bailey equipment, and the hauling distance.

4-17. **Timber Construction.** Dimensioned lumber is available through the military supply system or can be procured locally in most situations. Timber is extremely versatile for repairs. If the repairs are correctly designed and constructed, timber can be configured to carry any weight classification if enough of it is available for the job. Timber has a versatile layout, is usually available, and does not tie up tactical equipment.

4-18. **Log Construction.** The weight-carrying capacity of log construction is acceptable if it is correctly designed and constructed and if sufficient material of adequate size exists. Although more time is required to use logs than dimensioned lumber, logs may be easier to obtain and more economical.

4-19. **Existing Piers.** Bridge superstructures are much more susceptible to military demolition than piers. A bridge's superstructure may be nearly

destroyed while the piers remain intact and capable of supporting military bridging (emergency or otherwise). Existing piers used for repair must be sound all the way up to the level finally selected for the supporting pedestal. Most arch bridges or suspension bridges with masonry towers will have ragged tops. The tops of these towers must be made into level platforms or must be made usable. Offset the tops before using them as supports for military bridging.

**4-20. Dirt or Rock Fill.** An easy method of spanning gaps over dry crevices, shallow streams, or waterways with very low velocity is to fill the gap with dirt or rock. Except in extreme emergencies, make provisions for the passage of water that may be dammed by such a structure.

**4-21. Other Materials and Expedients.** There are many methods for applying local materials to repair gaps in bridge decks. Suitable solutions may simply require ingenuity on the part of the engineers and construction force.

## REPAIRING PIER FAILURES

**4-22.** Demolitions, collisions, floods, debris, ice, or scour can cause pier failure. Grade and track-alignment requirements for railroad bridges present problems during pier repair that are not common in repairing highway bridges.

### Major Pier Settlement

**4-23.** To determine if settlement has stabilized or if it is likely to continue, investigate the cause of the settlement. If it appears that settlement is likely to continue, stabilize the base of the pier with rock cribs, piles, or spread footings. The superstructure can then be jacked up and supported on the cribbing at the top of the old pier, or a new pier can be built around the old one.

### Pier Failure, Top Portion

**4-24.** Failure of the top portion of the pier (where the superstructure rests) occurs on masonry piers. To repair this condition, jack the superstructure up off the pier, square the top of the pier, and place cribbing on top of the masonry to support the superstructure.

### Scour

**4-25.** Excessive scour is a problem that has caused many bridge failures throughout the world. When enough soil is removed through water action around the pier, the pier fails. See *Chapter 7* for methods of preventing scour.

### Expedients

**4-26. Standard Parts.** Many standard military-bridge items are extremely useful in emergency pier construction. The most adaptable construction item is the Bailey-type component (*FM 5-277*). AFCS steel trestles also are versatile and are quickly assembled into many sizes, shapes, and capacities for use as emergency piers.

**4-27. Timber Piers.** Standard, dimensioned lumber can be used to make bents or crib piers for emergency pier construction. Such timbers lend

themselves to design flexibility, although more time is required to use dimensioned lumber than standard parts.

**4-28. Log Piers.** Timber from local sources can be effective for emergency construction of piers and bents. However, more time is required in their use than for any of the standard parts.

## STRINGER SUPPORTS

4-29. Adding stringers increases the carrying capacity of the flooring. The disadvantage is that this method almost always requires removing the flooring. Analyze existing stringers according to the methods described in *paragraph 3-45* for timber, *3-62* for steel, and *3-67* for composite. Determine the number and size of necessary additional stringers by the design methods described in *Chapter 6*.

## CONSIDERATIONS

4-30. Some viable structures require one additional stringer per lane. Place these stringers about one-fourth the lane width from each side of the lane's centerline.

4-31. Different materials have different stiffnesses, which must be considered when adding stringers. Steel has a much greater modulus of elasticity than timber, so its resistance to deflection is greater. Timber and steel stringers used together to support a bridge floor must have the same deflection resistance. The load each material carries is, among other factors, proportional to its deflection. The timber stringer will carry much less than its proportional share of the applied load, forcing the steel stringer to carry more than its proportional share. Avoid overstressing by using stringers similar to the original stringers' depth and material.

4-32. If available materials are not the same as those used for the original design, the decks of some spans may have to be removed for use on other spans of the structure and new decking may have to be placed on the empty spans. Each span of the structure will then have like members.

4-33. Connections for standard construction and material combinations are typical. However, problems such as connecting timber stringers to steel floor beams may require special solutions in the field. See *Chapter 9* for additional information.

## REPAIRING CONTINUOUS SPANS

4-34. When stringers that are continuous over two or more spans have been damaged, they can be replaced with noncontinuous stringers that function as simply supported stringers. Slightly heavier (and in some cases deeper) stringers may be required since the maximum moments under loads are higher near the midspan for simply supported spans than for continuous spans. No additional strength will be required for shear because end shear is less in simple spans than in continuous spans. Simply supported stringers should be designed the same as for new bridges (*Chapter 6*).

4-35. Follow these steps to repair a bridge deck that is supported by steel stringers.

**Step 1.** Jack up the deck to clear the stringers.

**Step 2.** Place new stringers alongside the existing stringers.

**Step 3.** Remove the existing stringers.

**Step 4.** Move the new stringers laterally into the correct position.

**Step 5.** Lower the bridge deck to rest on the new stringers.

4-36. Bridge decks constructed of reinforced concrete T-beams are not usually salvageable because the slab is destroyed if it separates from the stem. Replace this type of structure if the damage is extensive. To avoid removing the damaged structure, place a new steel-stringer deck on top of the existing concrete deck, with at least 1 inch of clearance between the stringers and the concrete (add bearing plates on the concrete deck over the supports). This expedient method can only be used when there are adequate end bearings for the new stringers. Substructures adequate for continuous structures also will be adequate for simple spans, assuming that the dead load causes no further settling.

## REINFORCING TRESTLE BENTS

4-37. After strengthening the superstructure, consider whether the substructure bents need strengthening to carry the increased load. Reinforce posts by nailing 2- x 6- or 2- x 8-inch planks to the posts (*Figure 4-4*) and by adding another post if necessary (*Figure 4-5*). Drive solid, tapered wedges between the top of the new post and the cap beam, and nail them in place to prevent dislodgment.

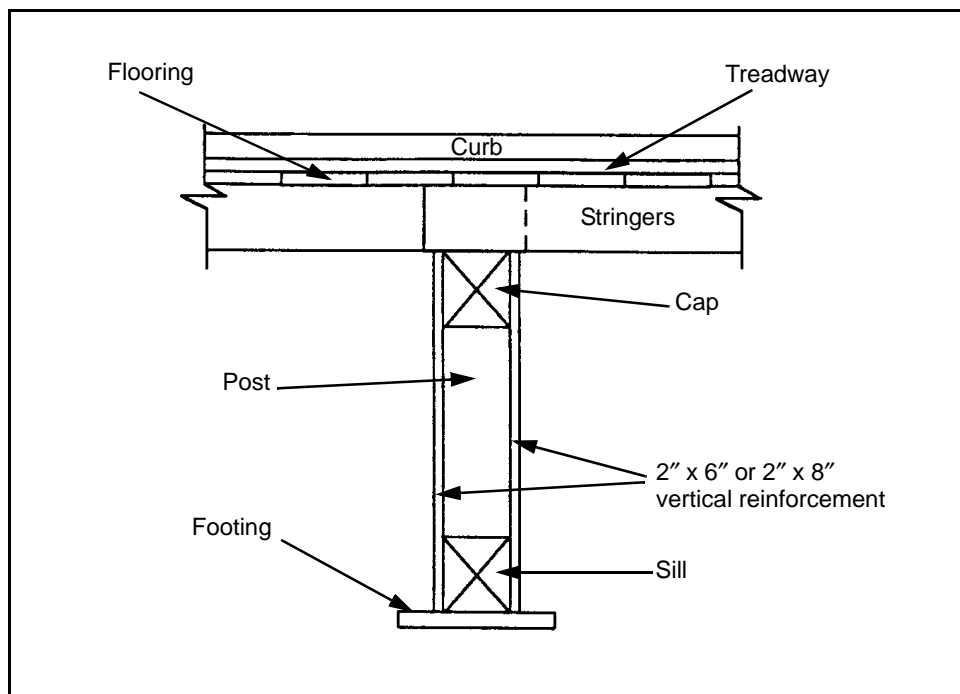


Figure 4-4. Timber-Trestle Reinforcement Post



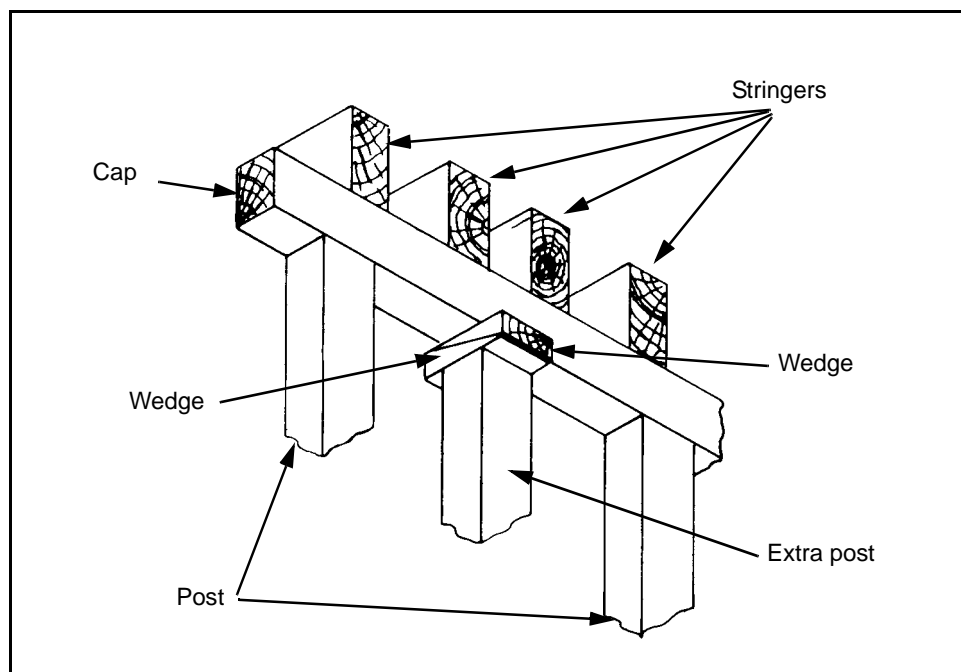


Figure 4-5. Installation of an Extra Post

## STRINGER REINFORCEMENT

4-38. Stringer reinforcement can be accomplished in several different ways. The paragraphs below describe various methods.

### EXTRA FLOOR BEAM

4-39. An extra floor beam can be added on a truss or girder bridge if the beam can be supported and connected at the panel points. Place the beam beneath the stringers so that it carries the stringer loads by bearing only instead of with a shear connection, which is typical of regular construction. Installing the floor beam in a truss involves special problems, unless the bottom chord has been designed to carry loads between the panel points. In most cases, suspend the new floor beam from the tension rods that are connected at the panel points of the chord. The new stringer capacity depends on the moment and the shear capacities.

### KING OR QUEEN TRUSS

4-40. An inverted king or queen truss can supply additional stringer support (*Figure 4-6, page 4-10*). This type of support does not require a bent or pier, which is advantageous where a new support would be excessively tall or when footing conditions or stream velocity would create additional problems. The disadvantage of this method is that the truss requires the stringer to function as a member of the truss, which causes it to become a compression member resisting both direct and stress bending. All stringers used in the span should provide equal load-carrying capacities. The most practical king truss is one made of a short section of a standard timber bent, with a cap and sill.

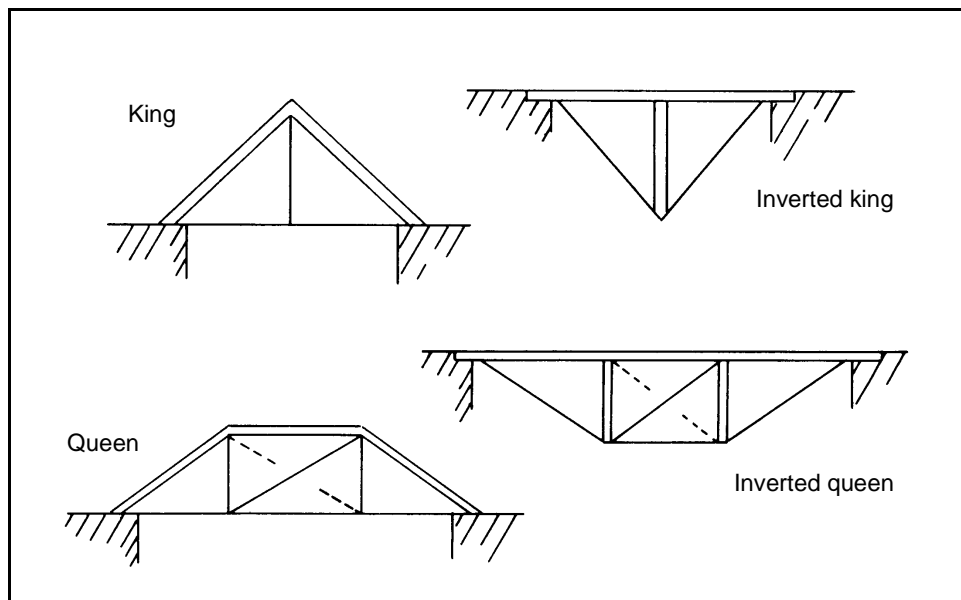


Figure 4-6. King and Queen Trusses

## A-FRAME

4-41. Several types of A-frames are effective for providing additional stringer support (*Figure 4-7*). A-frames may not require additional footings. Adequately brace substructure bents longitudinally for spans adjacent to those in which an A-frame is placed. Doing this helps the bridge resist the horizontal forces acting through the members of the frame.

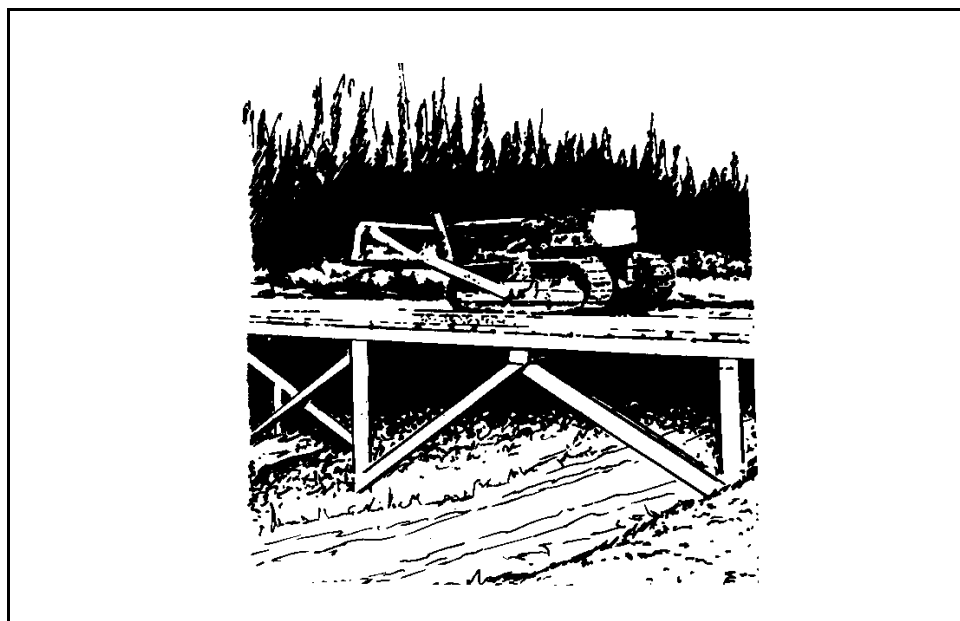


Figure 4-7. A-Frame

## KNEE BRACES

4-42. Use knee braces (*Figure 4-8*) the same as for A-frames. Firmly anchor the piers against lateral movement for this arrangement.

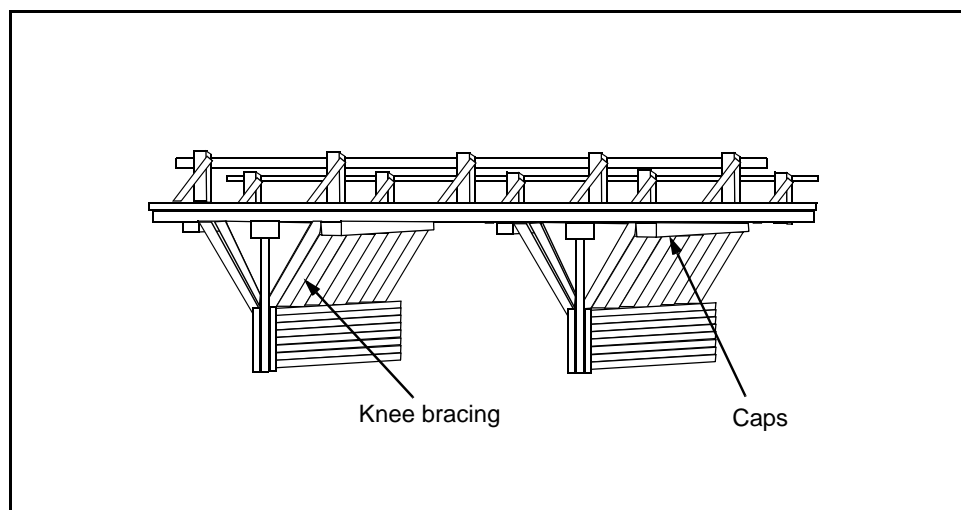


Figure 4-8. Knee Brace

## BENTS, PIERS, AND TOWERS

4-43. Bents, piers, and towers may also provide stringer support. See *Chapter 7* for additional information. The main consideration is the economy of time and material. The requirements for adequate footings or for tall structures may take more time and material than adding stringers to the superstructure.

## STEEL FLOOR-BEAM REINFORCEMENT

4-44. Floor beams are exceptionally difficult to reinforce because of the construction details and loading characteristics. Steel stringers connected to the webs of the steel floor beams prohibit placing additional beams beside the existing beams. One way to reinforce steel floor beams is to weld plates to the top and bottom flanges (if the two flanges can be exposed). Place additional beams (if necessary) below the existing floor beam if they can be adequately connected to the main supporting structure. If the stringers are above the existing floor beams, place additional floor beams beside the existing ones or on both sides of each (if necessary). The connections to the supporting structure may create a problem that must be solved according to the details of the particular structure involved.

## TRUSS REINFORCEMENT AND REPAIR

4-45. A truss is a major load-carrying structure composed of straight members intersecting at panel points. The straight members form triangles in which the primary stresses are tensile or compressive rather than flexural. The bottom chord is ordinarily a tension member throughout its length,

whereas the top chord is a compression member. The chords resist the moment in the truss span, while the web members (verticals and diagonals) resist the shear. Each member is designed to provide for the maximum direct stress that it is expected to resist.

4-46. Trusses are advantageous for long spans because they are able to carry greater loads, in proportion to their weight, than would be possible with solid members such as plate girders. Although the fabrication cost of trusses is high, their use reduces the overall dead load of the structure. Truss analysis is discussed in *Chapter 3*.

4-47. Trusses are often intact and require little repair. If a single member has been damaged it should be repaired. In some cases, a truss may be intact; however, a pier fails and the truss dislodges from its piers. In such cases, jack the truss back up onto its original pier or onto a repaired pier. Seldom can trusses be completely replaced. They are usually repaired or reinforced. In most cases, reinforcing the flooring and the stringers is satisfactory. However, the truss members may need to be reinforced if stress analysis indicates that the structure is inadequate and additional supports are not practical. Truss-member reinforcement may consist of—

- Replacing existing members with heavier sections.
- Increasing the capacity of existing members by adding material.
- Adding additional supports at panel points.

## INTERMEDIATE SUPPORTS

4-48. Additional intermediate supports are the simplest, most effective means of strengthening a truss (if the truss characteristics and the situation allow). The practicality of using intermediate supports will depend on the required height, spacing, footing conditions, stream characteristics, and so forth. Some situations could require more material and time than would be required for discarding the old span and building a new structure on the existing piers. The intermediate supports (pile piers, timber bents, towers, or any of the standard prefabricated steel components [such as the Bailey]) may be any of the various means of transferring loads to the ground.

4-49. Always locate intermediate supports at panel points. Supports located in other areas will produce bending stresses in the chord members, which will result in structure failure. Carefully select panel-point supports to avoid stress reversals. Determine the locations of the intermediate supports only after a structural engineer carefully analyzes the stresses resulting from the assumed location of supports. Should the analysis indicate that any members are inadequate to carry the resulting forces, change the support locations or strengthen the members.

## CONNECTIONS

4-50. Reinforcing connections is just as important as reinforcing members to avoid failure. Connections between steel tension and compression members are usually made with splice plates that are welded, riveted, or bolted to the members.

## REINFORCING COMPRESSION MEMBERS

4-51. The strength of a compression member depends on the cross-sectional area of the steel section and on the arrangement of the area about the section centroid. Considering buckling resistance, 1 square inch of steel that is 10 inches from the centerline is four times as effective as 1 square inch of steel that is 5 inches from the centerline. Member stiffness is a function of the member's smallest width. For example, the stiffness of a 12- x 16-inch rectangular section is governed by the 12-inch dimension. The stiffness is also affected by the ratio of the effective unsupported length of the least radius of gyration. The slenderness ratio is computed as follows:

$$R_s = \frac{KL}{r} \quad (4-1)$$

where—

$R_s$  = slenderness ratio

$K$  = effective length factor (Table D-9, page D-9)

$L$  = member length, in inches

$r$  = least radius of gyration, in inches (paragraph D-15)

4-52. Increase the stress-carrying capacity of a compression member by adding plates or shapes on the outside of the section and by adding extra plates to the existing member (Figure 4-9A). Assume that the added strength is proportional to the increase in area if the following conditions are observed:

- The plates or shapes are added on the outside of the section.
- The attachment (riveted or bolted) is designed to cause the new section and the old section to act together.
- The new member is continuous from one end to the other or is properly spliced.
- The end connections of the member are adequate for the new stress.

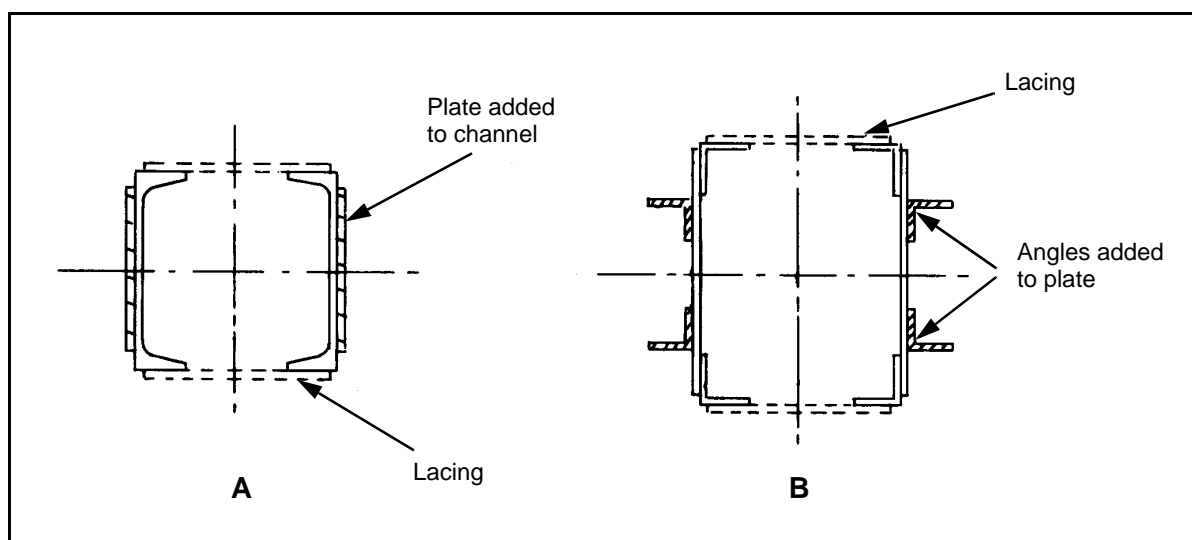


Figure 4-9. Strengthening Truss Members

4-53. Reinforce truss compression members as described in the example below. Reinforce an existing steel-truss compression member with riveted and bolted members (*Figure 4-9A, page 4-13*) to carry a total force of 350 kips. Each standard channel is 12 inches high and weighs 0.0207 kpf. The back-to-back distance of channels is 12 inches. The member length is 340 inches from panel point to panel point.

### Load Capacity

4-54. Use the steps in the following example to determine load capacity:

**Step 1.** Find the area for the two channels using the web area (*Table D-2, pages D-3 and D-4*). For this example, the channel area is 12.2 square inches.

**Step 2.** Find the radius of gyration in *paragraph D-15*. For this example, the radius of gyration is 4.61 inches.

**Step 3.** Find the slenderness ratio as follows:

$$R_s = \frac{KL}{r} = \frac{0.75(340)}{4.61} = \frac{255}{4.61} = 55.31 \quad (4-2)$$

where—

$R_s$  = slenderness ratio

$K$  = effective length factor (*Table D-9, page D-9*)

$L$  = member length, in inches (*paragraph 4-53*)

$r$  = radius of gyration, in inches (*step 2*)

**Step 4.** Find the allowable unit stress for the column (assume American Society for Testing and Materials [ASTM] A36 steel) from *Table 3-6, page 3-25*. For this example, the allowable unit stress is 17.9 ksi.

**Step 5.** Find the maximum compressive load as follows:

$$P = F_a A = 17.9(12.2) = 218 \text{ kips} \quad (4-3)$$

where—

$P$  = maximum compressive load, in kips

$F_a$  = allowable axial compressive stress, in ksi (*step 4*)

$A$  = area of the two channels, in square inches (*step 1*)

### Plate Additions

4-55. Recompute for load capacity if plates are added to the members. For this example, use the numbers from the example in the previous paragraph. Compute as follows:

**Step 1.** Find the total channel area by adding two 11- x 1/4-inch plates to the original channel area:

$$A_t = A + A_p = 12.2 + 2[11(0.25)] = 17.7 \text{ sq in} \quad (4-4)$$

where—

$A_t$  = total channel area, in square inches

$A$  = original channel area, in square inches (paragraph 4-54, step 1)

$A_p$  = plate area, in square inches

**Step 2.** Use 4.61 inches for the radius of gyration (paragraph 4-54, step 2).

**Step 3.** Use 55 for the slenderness ratio (paragraph 4-54, step 3).

**Step 4.** Use 17.9 ksi for allowable unit stress (paragraph 4-54, step 4).

**Step 5.** Find the maximum compressive load as follows:

$$P = F_a A_t = 17.9(17.7) = 316.8 \text{ kips} \quad (4-5)$$

where—

$P$  = maximum compressive load, in kips

$F_a$  = maximum compression, in ksi (step 4)

$A_t$  = total area of the two channels, in square inches

4-56. The result is an increase of 45 percent over the original capacity of 218 kips. Bolt, rivet, or weld the added 1/4-inch plates rigidly to the channels to make them part of the member. Connect the reinforcing plates with sufficient strength to develop the plates. With the length as the center-to-center spacing of the bolts, rivets, or welds, space the connecting elements between the ends so that the slenderness ratio is not greater than the entire member.

## REINFORCING TENSION MEMBERS

4-57. Tension members are often steel bars, rods, wire, or cable. Arrangement of the area has no great effect on a tension member. Increase the area by placing the rods or the cables alongside the existing members and tightening them with turnbuckles. The truss tension member shown in *Figure 4-9B* consists of two 18- x 3/8-inch plates and four 3- x 3- x 3/8-inch angles. The example below further explains reinforcing tension members.

### Area of the Tension Member

4-58. Compute the area of the tension member as follows:

$$A_t = N_{pl} A_{pl} + A_a N_a = 2(18)\left(\frac{3}{8}\right) + 4(2.11) = 21.94 \text{ sq in} \quad (4-6)$$

where—

$A_t$  = area of the tension member, in square inches

$N_{pl}$  = number of plates

$A_{pl}$  = plate area, in square inches

$A_a$  = angle area, in square inches

$N_a$  = number of angles

**Maximum Tensile Load**

4-59. Compute the maximum tensile load as follows:

$$P_I = F_t A_I = 27(21.94) = 592.38 \text{ kips} \quad (4-7)$$

where—

$P_I$  = maximum tensile load, in kips

$F_t$  = allowable tensile strength for the steel, in ksi (Table 3-6, page 3-25). For this example,  $F_t = 0.75F_y$ . Using A36 steel,  $F_y = 36$ ; therefore,  $F_t = 27$ .

$A_I$  = total area of the tension member, in square inches

**Angle Addition**

4-60. Add four 2 1/2- x 2 1/2- x 1/4-inch angles and recompute.

**Step 1.** Find the tensile area of the angles as follows:

$$A_2 = N_a A_a = 4(1.19) = 4.76 \text{ sq in} \quad (4-8)$$

where—

$A_2$  = total area of the angles, in square inches

$N_a$  = number of added angles

$A_a$  = area of each angle, in square inches

**Step 2.** Find the total member area as follows:

$$A = A_I + A_2 = 21.94 + 4.76 = 26.7 \text{ sq in} \quad (4-9)$$

where—

$A$  = total member area, in square inches

$A_I$  = area of the tension member, in square inches

$A_2$  = area of the angles, in square inches

**Step 3.** Find the maximum tensile load as follows:

$$P = F_t A = 27(26.7) = 720.9 \text{ kips} \quad (4-10)$$

where—

$P$  = maximum tensile load, in kips

$F_t$  = allowable tensile strength for the steel, in ksi (Table 3-6).

For this example,  $F_t = 0.75F_y$ . Using A36 steel,  $F_y = 36$ ; therefore,  $F_t = 27$ .

$A$  = total member area, in square inches

The result is a 22 percent increase over the original force of 636 kips. End connections must develop the full strength of each reinforcing angle, but intermediate connections may be located at nominal spacing.



## REPLACING DAMAGED MEMBERS

4-61. Bent or twisted steel-truss members may be impossible to repair while they remain in the truss. Remove such members from the truss by dislodging them from the end gusset-plate connections. Straighten bent and twisted parts or repair damaged and broken parts, if possible. It is usually best to replace such members with identical fabricated sections. A truss member with bolted connections is relatively easy to remove. In riveted trusses, cut off the rivet heads and force the rivet shank out. Truss members with welded end connections are nearly impossible to remove. If the truss is to remain in position while the damaged members are replaced, try to prevent truss failure when removing the damaged members. Use cribbing under the truss where the replacements are being made (if the site conditions permit crib construction). Otherwise, use straps or cables to carry the dead-load stress of the removed member.

## FLOORING REPAIR

4-62. The flooring of existing civilian bridges is usually designed to conform to the bridge's capacity. However, the difference of military loads and wheel arrangements of military vehicles may require heavier floors than those assumed for a given stringer design. The reinforcement of the main bridge members may require that the flooring be strengthened for the desired MLC. Further, bridge floors in existing structures may have considerable wear or damage that greatly reduces its usefulness. For example, many timber floors in civilian structures consist of a single layer of decking, without a tread to protect the deck from wear. Always check the floors during a bridge analysis or classification.

## TIMBER

4-63. Timber is the most common bridge flooring in foreign countries. A popular form consists of one layer of decking, perpendicular to the bridge centerline, without an added wearing surface. When wearing surfaces exist, they may be of several types (ribbon tread or a tread covering the entire surface) that are similar to US standard military construction for semipermanent bridges. Other surfaces may consist of bituminous macadam that is applied monolithically or is in preformed planks. The use of treated or untreated wood blocks is also common.

4-64. Another method is to reinforce existing timber floors with an additional layer of decking and tread. This method may require removing the original wearing surface. The most practical solution in most cases is to replace the existing floor with a timber floor. If standard lumber is not available, use local lumber or squared logs.

## STONE MASONRY

4-65. In some parts of the world, bridges are built almost exclusively of stone. Often they are a simple masonry-arch bridge with a horizontal deck. The flooring for these bridges is often cobblestone or larger stones set over a rubble fill between the supporting arch and the road surface. Failure may occur because of wear, stone dislodgment, failure of supporting fill, military

demolition, or accidents. If the bridge is in place, the floor is likely to be intact except for potholes, which may be patched with concrete. Bituminous macadam or concrete topping makes an ideal wearing surface. Flooring reinforcement for this type of bridge is not necessary except for installing a wearing surface.

## CONCRETE

4-66. In Europe, some concrete bridge floors have thinner sections than those in the US. Stringer and floor replacements are frequently required to repair these bridges.

## MASONRY-PIER AND -ABUTMENT REPAIR

4-67. Permanent masonry piers and abutments are seldom destroyed. Use them to the fullest extent possible in bridge repair. First, clear damaged piers and abutments of all loose debris. Then clean them down to solid material, leaving a level platform. Some damaged structures may require two or more benched levels, depending on the details of the structure. Standard steel panels and trestle units make ideal combinations for either constructing new piers and abutments or repairing existing structures.

4-68. Large cracks in masonry may not be serious, depending on the type of crack and the direction of the forces on the structure. For example, a horizontal crack in a massive masonry pier may not be serious, but it may be critical in an abutment. Vertical cracks may be permissible under certain conditions. Large diagonal cracks are usually highly undesirable, unless they are in the wing walls of an abutment where they are easily repaired.

4-69. Repair cracks by banding the structure with straps (steel or iron) or beams pulled tightly (by straps) in the direction that tends to close the crack. Grout or seal cracks to allow bearing and shear stresses to transfer and to prevent the accumulation of water inside the structure.

## BAILEY-TYPE COMPONENT

4-70. The Bailey-type component is ideal to use in repairing destroyed and damaged piers and abutments. The basic unit and the various special parts lend themselves to an infinite number of combinations that provide the desired capacity, height, or arrangement. *FM 5-277* describes the components and their uses for these purposes. *Figures 4-10 and 4-11* show ways to use the Bailey panels for repairing damaged piers and abutments.

## HYDRAULIC EFFECTS OF ADDITIONAL SUPPORTS IN WATERWAYS

4-71. Waterways usually adjust themselves to existing piers or abutments. However, new piers and abutments may have an immediate influence on the hydraulic behavior of a waterway. Any obstruction placed in flowing water creates turbulence and slows the flow near the obstruction proportionately greater than the actual width of the object. Some bridging situations require constructing many new piers, which appreciably restrict water flow. The volume of water that must pass through the bridge site cannot be altered except by diversion. If the area is constricted by piers, the waterway must

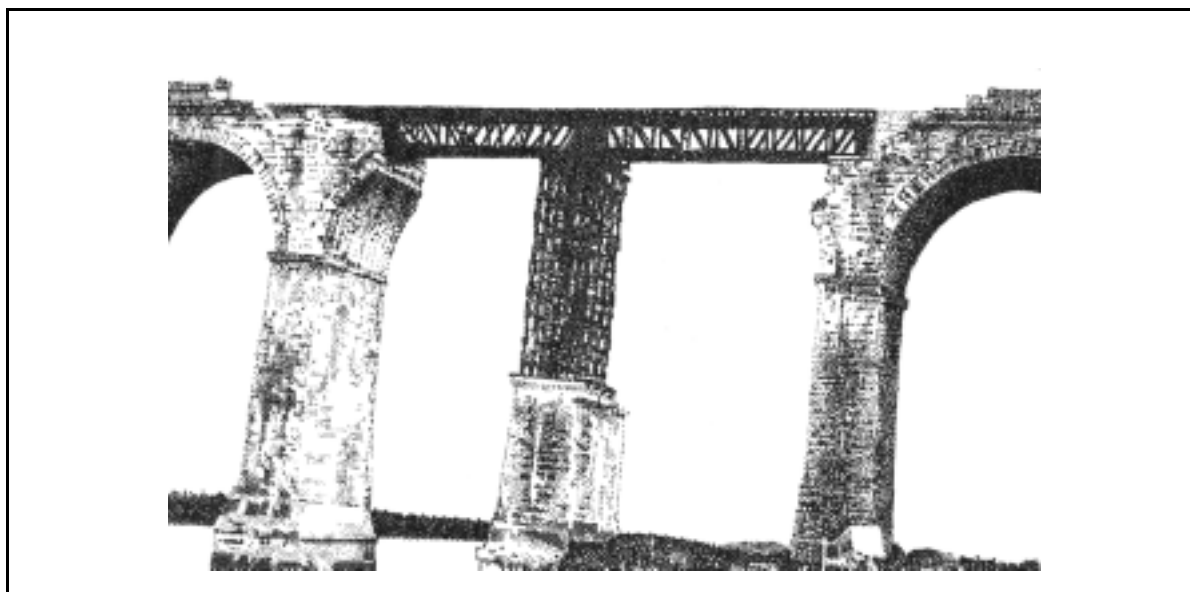


Figure 4-10. Bailey Panels Over a Broken Masonry Arch

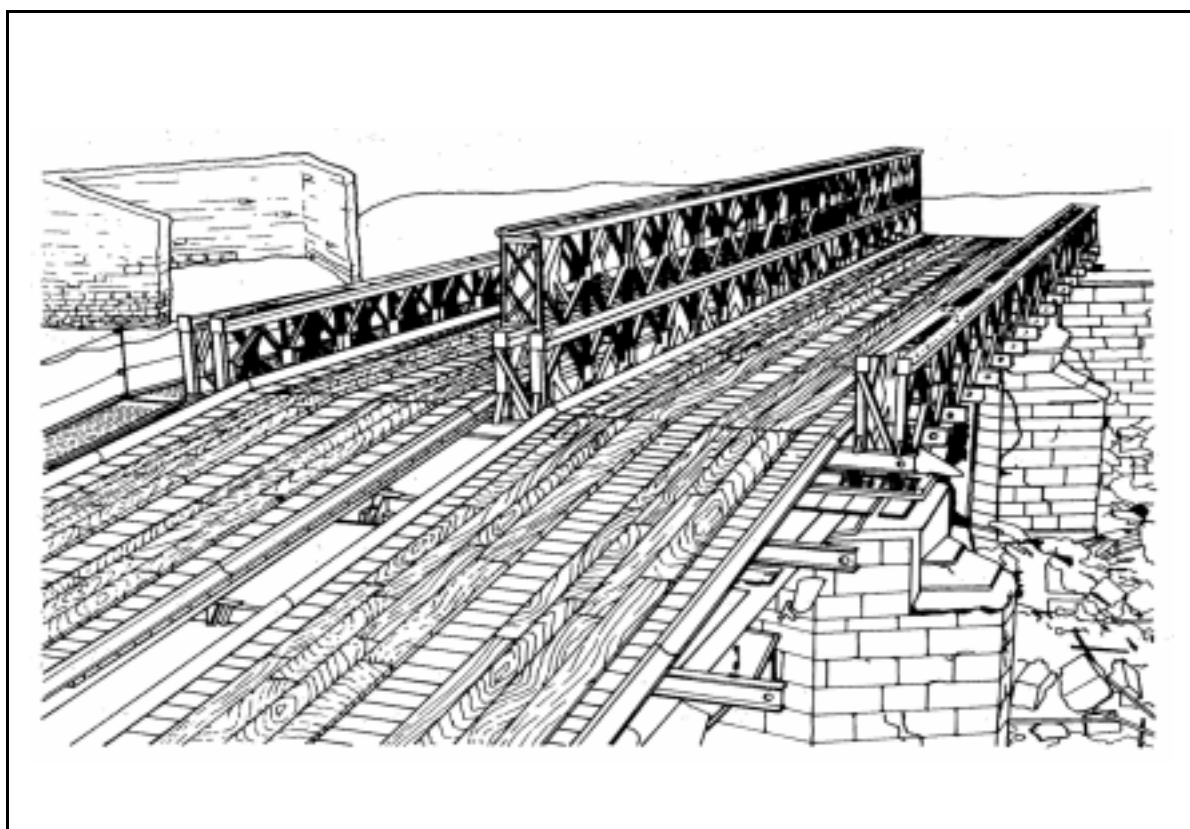


Figure 4-11. Bailey Panels Over a Demolished Masonry Arch

retain its flow by increased water depth and velocity between obstructions. Turbulence and increased velocity cause scouring and require special protective measures such as those outlined in *Chapter 7*.

4-72. A stream's ability to carry sediment varies with the velocity. For streams with a high-sediment content, local velocity reduction may cause the sediment to drop. This deposited sediment creates an additional obstruction that modifies the water flow. Therefore, it is best to keep new obstructions to a minimum in flowing water. When bridging considerations require a large number of new piers, it may be necessary to divert part of the water through culverts that are placed in the approach fill.

## MASONRY-ARCH-BRIDGE REPAIR

4-73. Masonry bridges present problems in reinforcement and repair different from other types of bridges. Piers of multiple-span masonry-arch bridges are designed so that the horizontal components of dead-load thrust from the two arches meeting on a pier balance each other. When a span is destroyed, the unbalanced horizontal forces from the remaining spans (arches) tend to overturn the piers on either side of the gap, causing collapse (unless suitable repairs are made). Many masonry-arch bridges have piers thick enough to eliminate reinforcing the piers that are adjacent to the demolished arches. If piers are thicker than one-fifth the span and are in good condition, test loadings are recommended before undertaking reinforcement.

4-74. *Figure 4-12* shows the forces in a masonry arch. If a standing pier is a massive structure, assume that it is stable enough to withstand the horizontal dead-load thrust of the arch. Therefore, design the new construction to resist only the horizontal live-load thrust plus impact. The total horizontal force required to resist the horizontal live-load thrust on a pier, including impact, is the total of the horizontal dead-load and live-load thrusts. Both components are computed as follows:

$$H_{DL} = \frac{W_{DL}L}{8R'} \quad (4-11)$$

where—

$H_{DL}$  = horizontal dead-load thrust, in kips

$W_{DL}$  = dead load of the pier, in kips

$L$  = span length, in feet

$R'$  = rise of the arch, in feet

and—

$$H_{LL} = \frac{W_{LL}L}{4R'} \quad (4-12)$$

where—

$H_{LL}$  = horizontal live-load thrust, in kips

$W_{LL}$  = live load of the pier, in kips

$L$  = pier length, in feet

$R'$  = rise of the arch, in feet

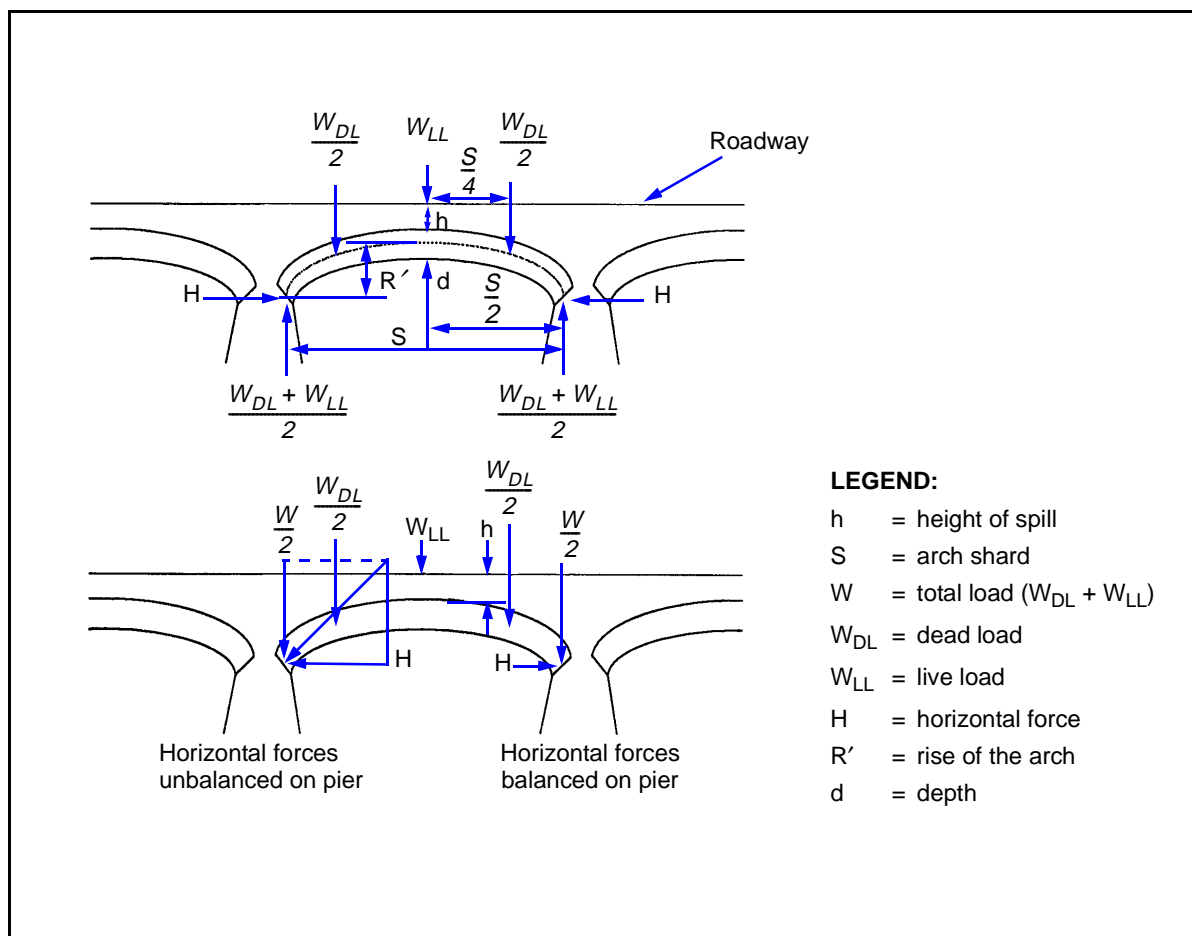


Figure 4-12. Forces in Masonry Arches

## REPAIR METHODS

4-75. There is not a "most suitable" method of repairing masonry-arch bridges. After considering the acting forces, available materials, site conditions, and results of previous solutions, use the methods discussed below (individually or in combination) to solve the problem.

### Demolition

4-76. Where all arches but one of a multispan bridge have been destroyed, demolish the remaining arch (especially if it is shattered). Complete the demolition before materials and equipment to be used for reconstruction arrive on the site.

### Ties in Adjacent Arches

4-77. Unbalanced horizontal live-load thrust can be distributed to interior piers by placing tie rods across the spans next to the gap. This is the best method if rock drills are available. The tie rods allow a crane to repair the

main gap on the spans safely. Place the tie rods at about the level of the springing lines and anchor them to the piers by any of the following methods:

- **Tie rods through piers.** Connect the ends of the tie rods to the steel wall plates or the beams extending across the back face of the piers (*Figure 4-13*). This method is not practical if heavy rock drills are not available.
- **Tie rods attached to steel plates.** Attach the tie rods to the steel plates that are anchored to the sides of the piers by the bolts that are set in concrete (*Figure 4-14*). Clusters of light steel rails also make good tie rods (*Figure 4-15*).
- **Tie rods around piers.** Bend the tie rods around the piers where they bear against a frame that is supported by pieces of rail set in the face of the pier (*Figure 4-14*).
- **Tie rods attached to I-beams.** Attach the tie rods to the I-beams that extend across the back face of the pier (*Figure 4-16*).
- **Turnbuckles and wedges.** Tighten and maintain the tension in tie rods with turnbuckles, tie rods with threaded ends, or wedges. Threaded connections should be as strong as the ties in tension. In a long span, use sag rods to support the rods that are under the arch (*Figure 4-13*).

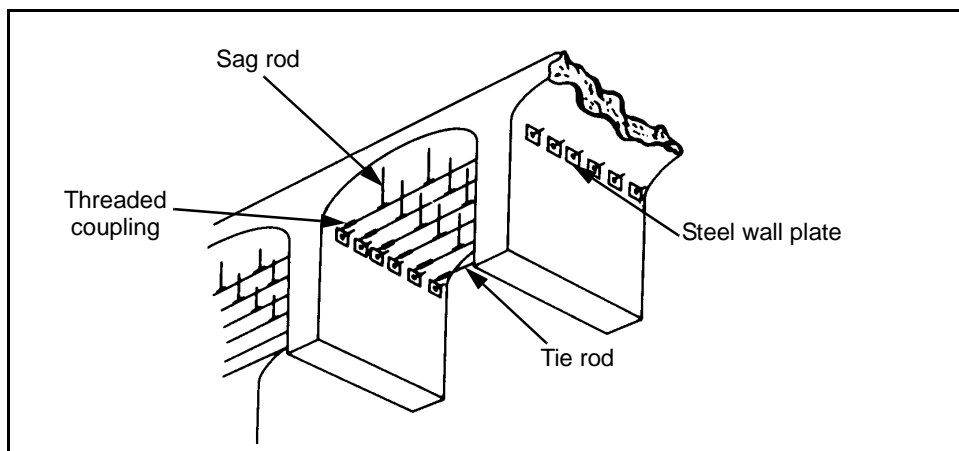
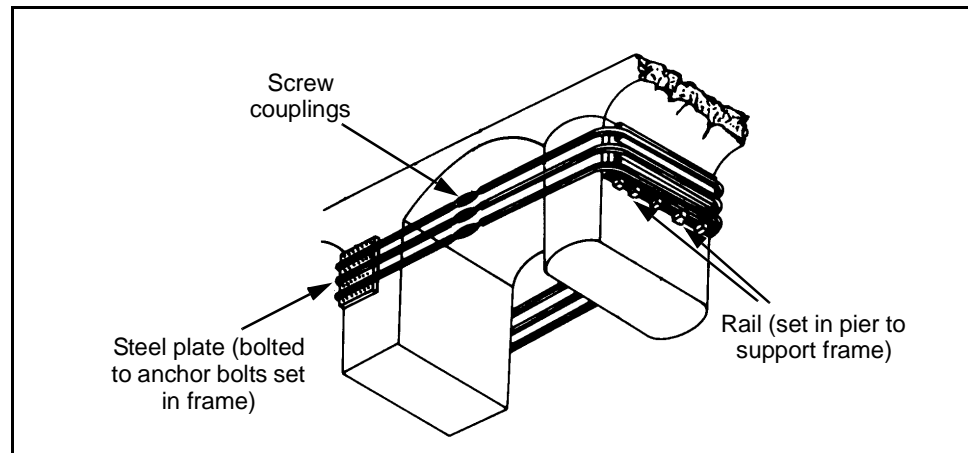
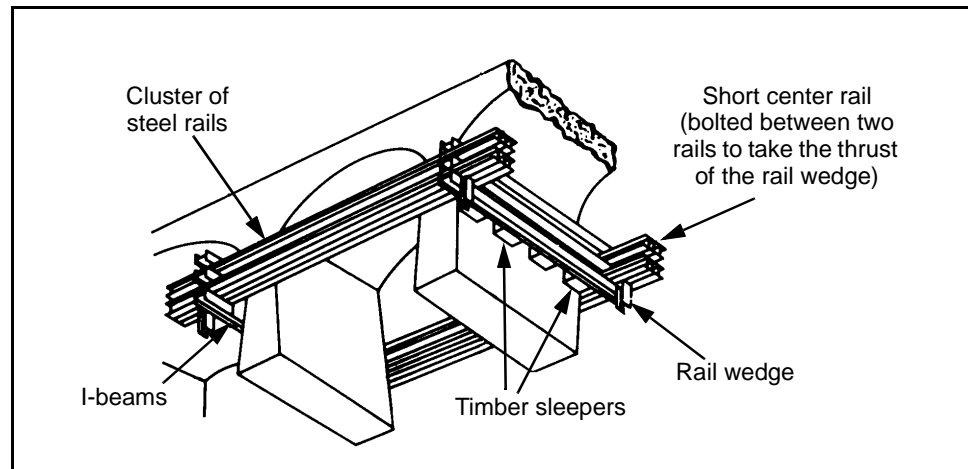
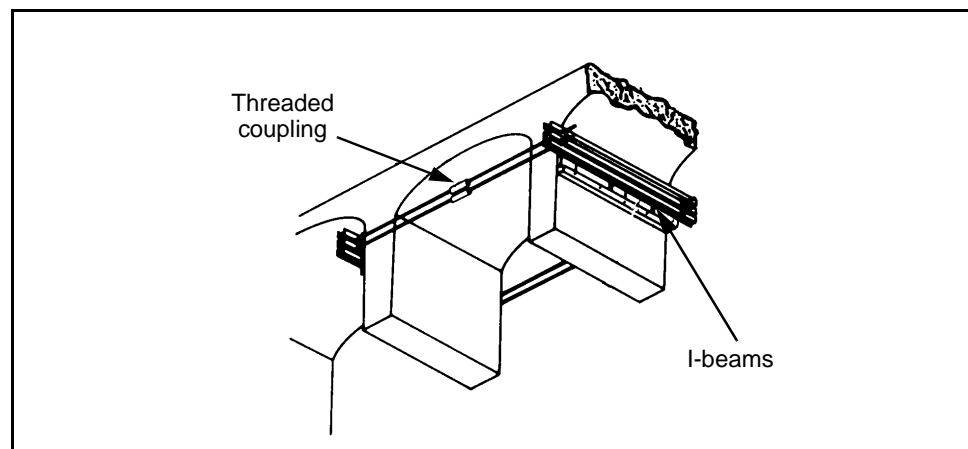


Figure 4-13. Tie Rods Connected to Wall Plates

### Struts Across the Gap

**4-78. Spans Under 25 Feet.** When the main gap is short and materials are available, timber struts placed across the gap at the springing level provide resistance against the unbalanced horizontal thrust (*Figure 4-17, page 4-24*). The struts bear against transverse wall beams that are supported on trestle bents erected against the inner face of the piers. Brace the structure longitudinally and laterally, and use wedges to obtain the full bearing of the strutting against the face of the piers.

**4-79. Spans Over 25 Feet.** Place trusses between the struts vertically (*Figure 4-18, page 4-24*), place intermediate ground supports, or use horizontal bracing. Arrange the intermediate supports to allow the demolished piers in the gap to be rebuilt and to support rebuilt arches.

**Figure 4-14. Bolts Set in Concrete****Figure 4-15. Tie-Rod Clusters****Figure 4-16. Tie Rods Attached to I-Beams**

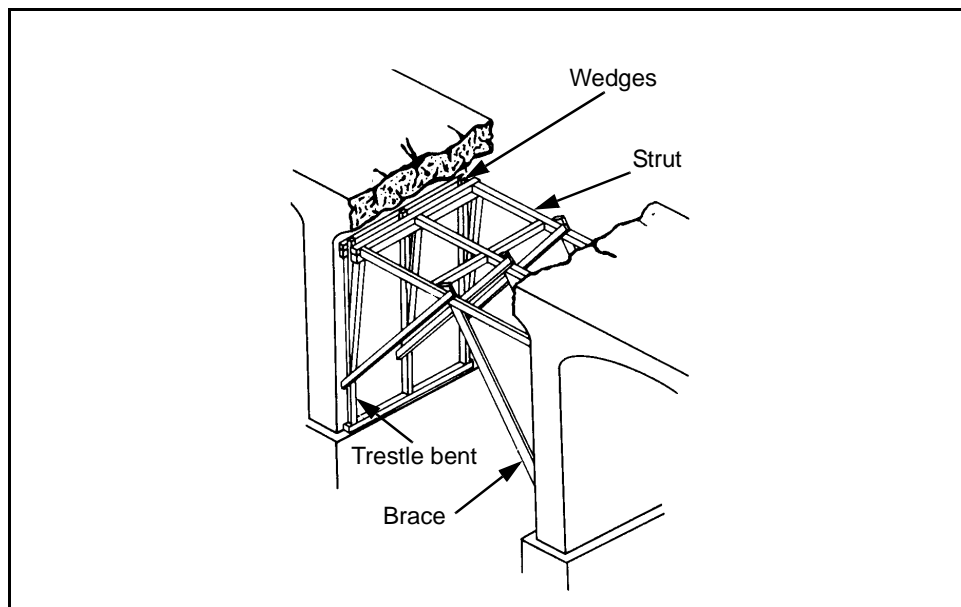


Figure 4-17. Timber Struts Across a Short Span

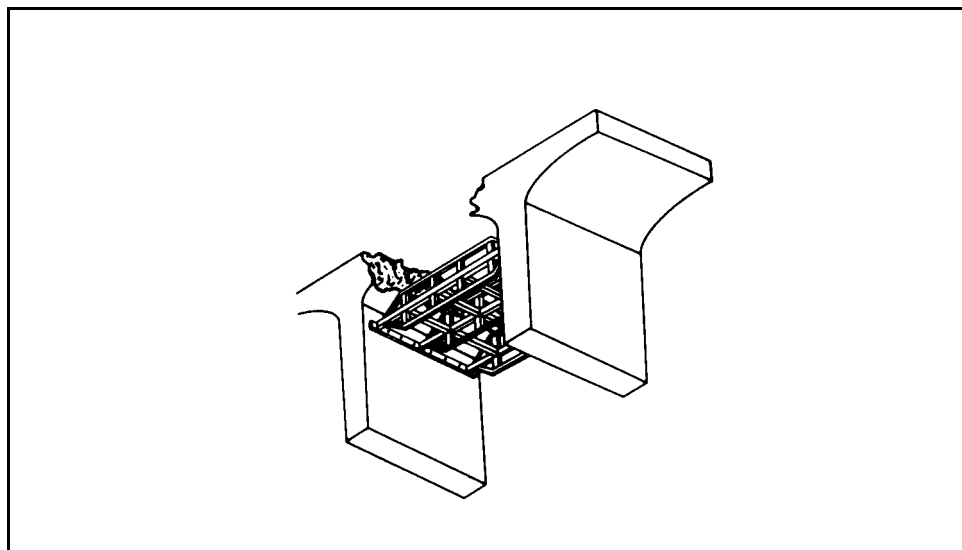


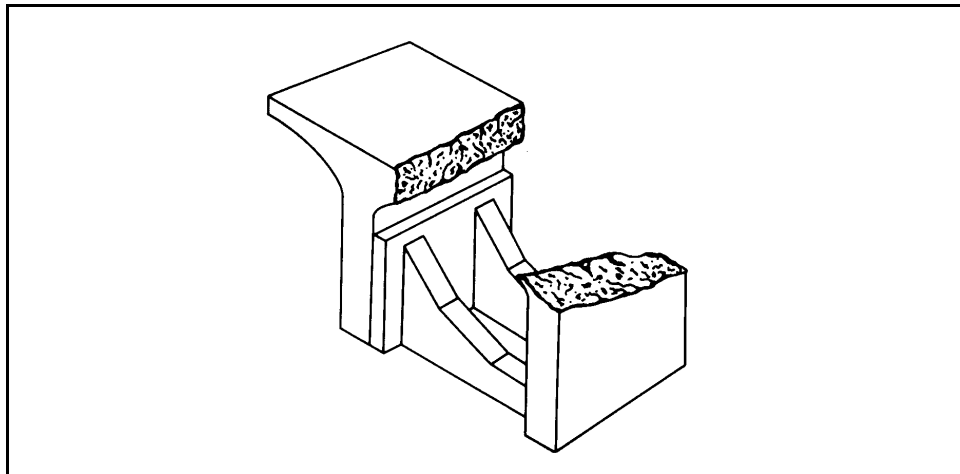
Figure 4-18. Trussed Struts Across a Long Span

**4-80. Buttresses and Shoring.** Demolishing several successive piers leaves a gap too wide for strutting. In such cases, construct a buttress wall or a shoring of mass concrete, rubble, masonry, or brickwork (*Figure 4-19*).

**4-81. Relieving Girders.** One of the easiest repair methods is to bridge the span next to the gap with relieving girders (*Figure 4-20*). Usually, the load will not have to be relieved from arches that are intact. However, in multiple-arch viaducts, relieving girders may be required on each side of the gap. Rail clusters; I-beam spans; plate-girder spans; or through-type, standard steel bridges are the best relieving girders, since low construction is essential.

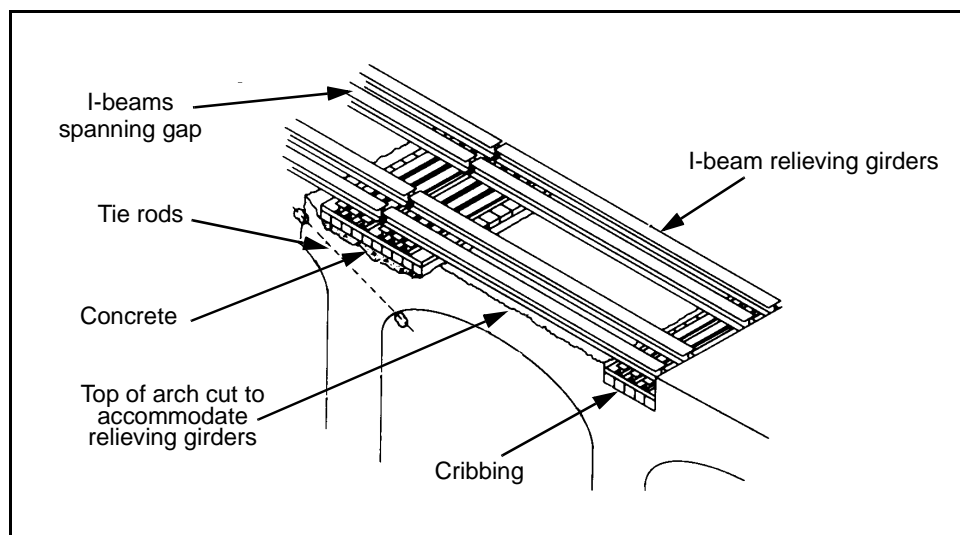


Simple spans should meet on the centers of the piers. Continuous-span bridges are supported on the centers of the piers.



**Figure 4-19. Masonry or Concrete Buttress**

4-82. Unless there is time to provide even bearing and to grout anchor bolts, construct timber bridge seats with the ends of the girders resting on them, rather than directly on the masonry. Level the damaged masonry until all cracked portions are removed, and fill the holes with concrete. A perfect finish to the masonry surface under the timber is not necessary.



**Figure 4-20. Relieving Girders**

4-83. **Centering in Adjacent Arches.** Use timber framework (centering) where spans across the gap are shattered. This will prevent the spans from deforming and relieve the adjacent piers from horizontal thrust (*Figures 4-21 through 4-23, pages 4-26 and 4-27*). Centering can be used in combination with tie rods and struts. If not using tie rods or struts to distribute the

horizontal thrust, ensure that the vertical framework supports are seated well down on the pier or independent of the pier under the arch. Design the framework to support the entire live load. The framework must support the arch in at least three places and must transmit the load to the piers. Do not wedge the framework too tightly against the arch because this may weaken the arch rather than strengthen it. Use only folding wedges to hold the bracing in place.

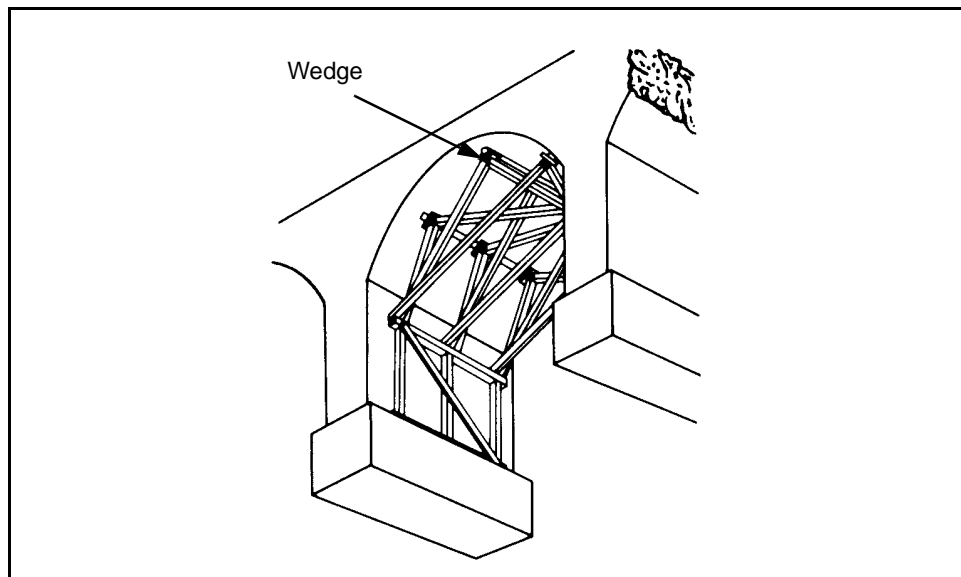


Figure 4-21. Pier Supports

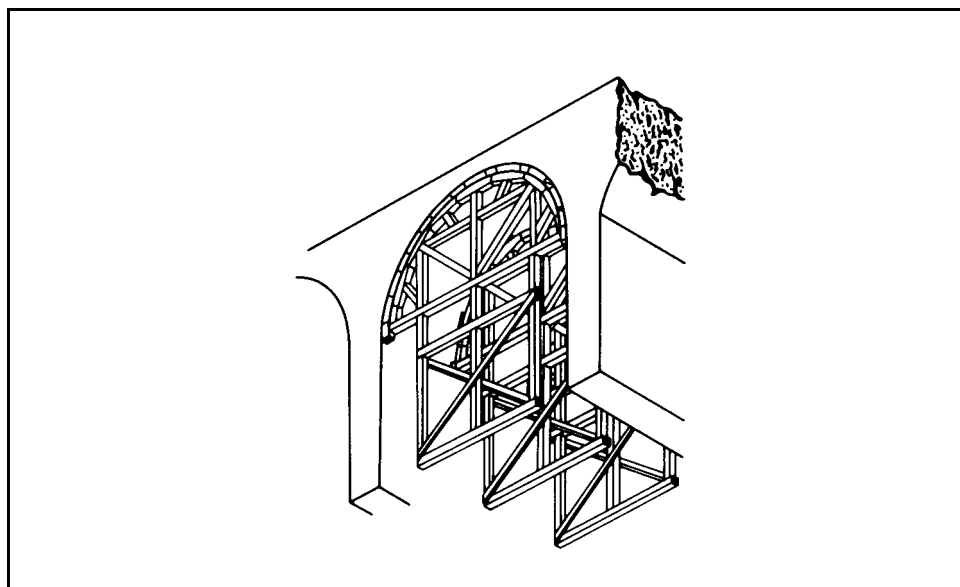


Figure 4-22. Intermediate Supports

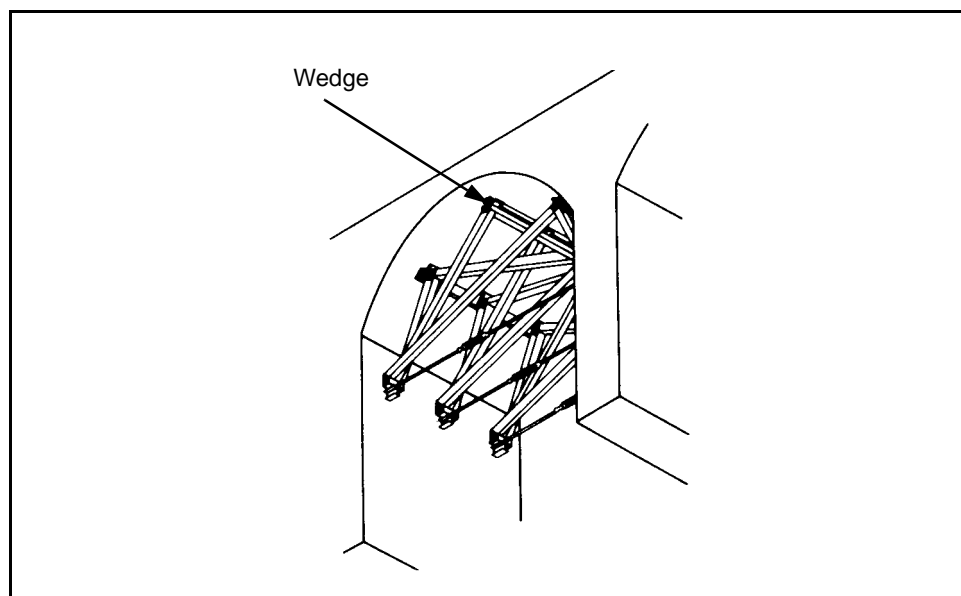


Figure 4-23. Tie Rods and Pier Supports

#### WIDENING MASONRY-ARCH BRIDGES

4-84. The main requirement for widening a roadway is that the existing structure has adequate strength to support the load of the additional roadway. Many arch bridges meet this requirement but are only wide enough for one lane.

4-85. *Figure 4-24, page 4-28, shows a revision of a typical masonry-arch deck with a new concrete slab placed over it and supported by the existing bridge deck. Wheel loads on the cantilevered portion of the slab may be distributed over a 3-foot length of slab in the direction of traffic. Determine the slab thickness and the size and spacing of the reinforcing bars in the top of the slab from the dead- and live-load moments. Determine these moments at Section A-A (Figure 4-24); do not rely on the concrete ribs for support. The ribs beneath the slab support the railing posts. Space these ribs 5 to 6 feet apart, center to center, and anchor them to the existing deck with anchored reinforcing rods set into drilled holes. Remove the existing railing or any portions of the existing structure that project above the roadway. Drill holes for the anchor rods and dowels, set the reinforcing steel in position, and place the concrete ribs and deck.*

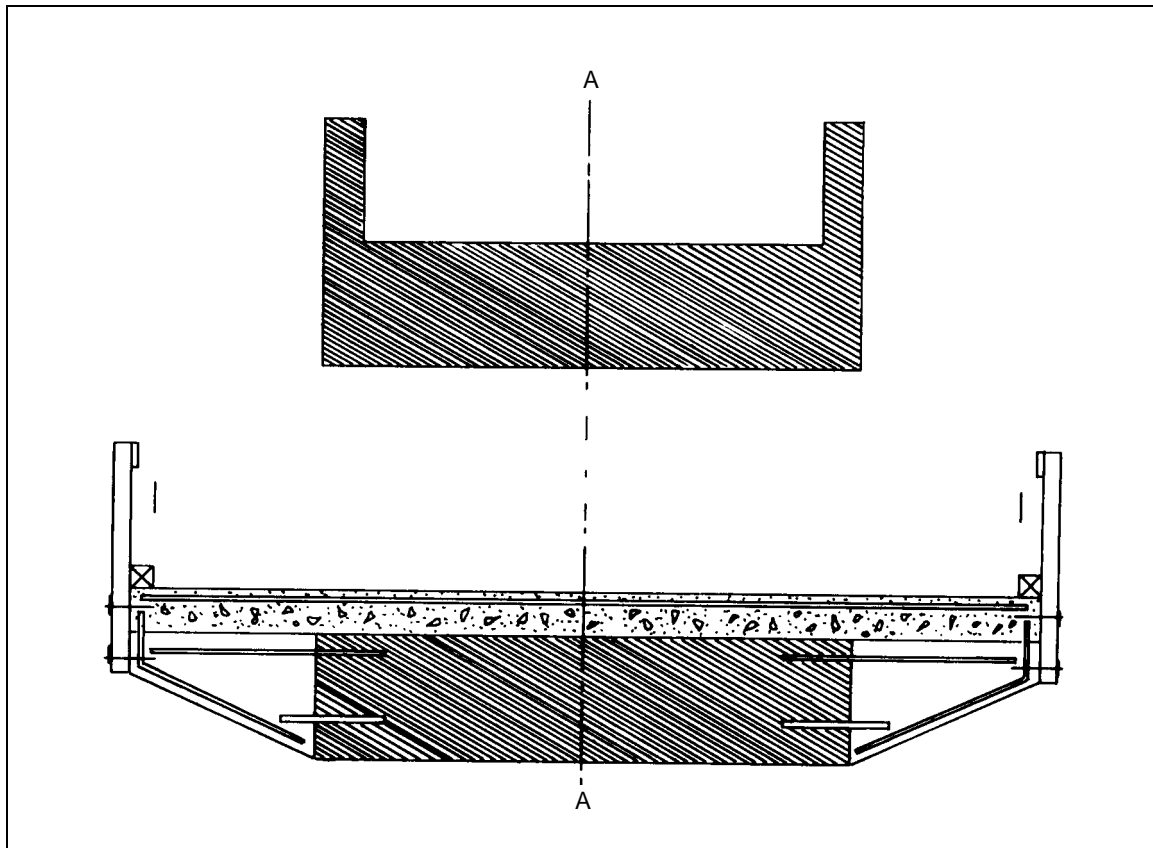


Figure 4-24. Widened Masonry-Arch Deck